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Multi-criteria Assessment of Facades' Alternatives: Peculiarities of Ranking Methodology

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Abstract

Alternative design solutions of buildings can be successfully evaluated applying Multiple Criteria Decision Making (MCDM) methods. There are a lot of methods available for supporting complex decisions in construction. However, previous research works show that various MCDM methods can produce different ranking results. Accordingly, three criteria of optimality, namely WSM (Weighted Sum Model), WPM (Weighted Product Model) and joint method of the latters called WASPAS (Weighted Aggregated Sum Product ASsessment) are applied, and their peculiarities are examined by comparing to well-known and reputed MOORA (Multiple Objective Optimisation on the basis of Ratio Analysis) method. A case study of ranking the facades for public and commercial buildings is presented.

Keywords: building facade; MCDM; WASPAS, MOORA.

1. Introduction

There are a lot of methods employed and case studies available when complex decisions are needed in construction. A multi-objective particle swarm optimization algorithm (MOPSO) with permutation-based representation to solve construction site layout planning problems is proposed by Xu and Li [1]. Hybrid multicriteria method for construction bidding process is presented by Seydel and Olson [2]. Bidding framework consists of pairwise comparison procedure to generate criterion weights and a linear transformation procedure to calculate relative scores for bidding alternatives. Ustinovichius et al. [3] suggests CLARA and UniComBOS methods for multiattribute comparative analysis of investment variants in construction. Zavadskas et al. [4] presents the process of selection the foundation instalment alternative, which have to be the most appropriate and safe for building which stands on the aquiferous soil. The solution of problem was made by applying Additive Ratio ASsessment (ARAS) method. Pan [5] employed triangular and trapezoidal fuzzy numbers and the α-cut concept to determine a suitable excavation construction method. A systematic prequalification procedure based on Fuzzy Set Theory to admit for tendering only competent contractor is presented in Nieto-Morote and Ruz-Vila [6].

To choose the best building's design alternative usually several different solutions are being considered. They should be evaluated in terms of a number of quantitative and qualitative criteria. Zhu et al. [7] aims at developing a new optimization method to building envelope design for the lowest carbon emissions of building operational energy consumption using

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orthogonal experimental design (OED) method. Donath and Lobos [8] created a new decision support system tool based on the building information modelling (BIM) software platform. This tool generates several options for building envelopes according to the parameters required and helps reduce the working time, increases confidence in the generated solution, and contributes to the exploration of alternatives in a short period of time. Also a new decision support system for the integrated assessment of thermal insulation solutions with emphasis on recycling potential is presented by Anastaselos et al. [9]. Using this tool it becomes feasible to optimize the end-of-life management of thermal insulation solutions, and to select, during the design phase of a new building, the optimal thermal insulation solution for each building element. Zheng et al. [10] proposed an improved grey relational projection method to select the optimum building envelope alternative. A combination weighting method combining the subjective weighting method and the objective weighting method is adopted to calculate the weights of the factors and sub-factors. The relative projection values of the alternatives are calculated. And the optimum alternative is obtained.

Selecting the best variant of facade for building is one of important questions in building design. Solution of a similar task was presented in previous researches [11-13]. Four facade's alternatives in terms of twelve criteria, involving physical, structural, economic, environmental and performance properties, were evaluated. Three criteria of optimality were applied and alternative decisions were ranked by Šaparauskas et al. [11-12]. Two criteria of optimality indicated the most preferable alternative; however the third criterion indicated the other alternative as the best one. Accordingly, the question remained unsolved. The similar problem was continued by Zavadskas et al. [13] and a joint method of the latters' criteria of optimality called WASPAS (Weighted Aggregated Sum Product ASsessment) was proposed as well as applied for ranking of facades. Previous papers and other research works [14-15] show that particular Multiple Criteria Decision Making methods can produce different ranking results. Further analysis is required to carry a reliable solution.

The aim of the current research is to test the reliability of previously proposed methodology and to carry the valid decision as concerns selection of the best design solution for facades of public or commercial buildings. The well-known and reputed MOORA method [16-17], consisting of the ratio system and the reference point approach as well as the full multiplicative form is presented and applied for the case study. The results of applied methods are compared and recommendations for the most preferable facade's alternative are presented.

2. Multi-objective optimization

2.1. Three criteria of optimality and WASPAS

The first criterion of optimality, i.e. criterion of a mean-weighted success [11-12] is similar to the well-known Weighted Sum Model (WSM) [18], [19]. It is a method for multiple criteria decision making, i.e. it is applied for evaluating a number of alternatives in terms of a number of decision criteria.

Suppose that problem is defined on m alternatives and n decision criteria. The relative significance (weight) of the criterion is denoted by w_j. Variable x_{ij} stands for the performance value of alternative i when it is evaluated in terms of criterion j.

The relative importance of alternative i, denoted as $Q_i^{(1)}$, is defined as follows [18-19]:

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} w_j, \tag{1}$$

where linear normalization of initial criteria values is applied, i.e.

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \tag{2}$$

if $\max_i x_{ij}$ value is preferable or

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}}, \tag{3}$$

if $\min_i x_{ij}$ value is preferable.

The second criterion of optimality, namely multiplicative exponential generalized criterion, in general coincides with Weighted Product Model (WPM) [19-20].

The relative importance of alternative i, denoted as $Q_i^{(2)}$, is defined as follows:

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\bar{x}_{ij}\right)^{w_j}. \tag{4}$$

A joint generalized criterion of weighted aggregation of additive and multiplicative methods was proposed [11], [12]:

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} = 0.5\sum_{j=1}^{n} \bar{x}_{ij} w_j + 0.5\prod_{j=1}^{n} \left(\bar{x}_{ij}\right)^{w_j}. \tag{5}$$

Supposing the increase of ranking accuracy and, respectively, the effectiveness of decision making, methodology for optimization of weighted aggregated function was proposed and the Weighted Aggregated Sum Product Assessment (WASPAS) method for ranking of alternatives was presented [13]:

$$Q_i = \lambda\sum_{j=1}^{n} \bar{x}_{ij} w_j + (1-\lambda)\prod_{j=1}^{n} \left(\bar{x}_{ij}\right)^{w_j}, \ \lambda = 0, ..., 1. \tag{6}$$

2.2. MOORA and the full multiplicative form

The MOORA method consists of the ratio system and the reference point approach [16-17].

In the ratio system each response of an alternative to the objective is normalized as follows:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \tag{7}$$

where x_{ij} – response of alternative i to objective j; $i = 1, 2, ..., m$; m — the number of alternatives; $j = 1, 2, ..., n$; n – the number of objectives (decision criteria); $\bar{x}_{ij}$ – a dimensionless number representing the normalised response of alternative i to objective j.

Next, for optimisation, in a case of maximisation the responses (weighted normalized criteria) are added and, in a case of minimisation, weighted normalized criteria are subtracted, respectively:

$$\bar{y}_i = \sum_{j=1}^{j=g} \bar{x}_{ij} w_j - \sum_{j=g+1}^{j=n} \bar{x}_{ij} w_j, \tag{8}$$

where $j = 1, 2, \ldots, g$ are maximised decision criteria; $j = g + 1, g + 2, \ldots, g + n$ are minimised decision criteria; w_j is the relative significance (weight) of the criterion; $\bar{y}_i$ stands for the calculated relative importance of alternative i with respect to all objectives according to the ratio system approach. An ordinal ranking of $\bar{y}_i$ shows the final preference of alternatives.

According to the second part of the MOORA, the maximal objective reference point approach is used. The desirable ideal alternative with coordinates r_j is formed selecting data from every decision alternative under consideration, considering optimization direction of every particular criterion.

Next, we apply normalization according to Eq. (7). Having $\bar{x}_{ij}$ the normalised response of alternative i to objective j and the relative significance (weight) of the criterion w_j, we are able to apply the Min–Max metric of Tchebycheff [21] for ranking of alternatives:

$$\underset{(i)}{Min}\left\{\underset{(j)}{\max}\left|r_j - \bar{x}_{ij} w_j\right|\right\}. \tag{9}$$

The third approach, i.e. the full multiplicative form as a part of MULTIMOORA, is applied as follows [22]:

$$U_i = \frac{A_i}{B_i}, \quad (10)$$

where U_i denotes overall utility of alternative *i.*

$$A_i = \prod_{j=1}^{g} w_j \bar{x}_{ij}, \quad (11)$$

$$B_i = \prod_{j=g+1}^{n} w_j \bar{x}_{ij}, \quad (12)$$

where $j = 1, 2,\dots, g$ are maximised decision criteria; $j = g + 1, g + 2,\dots, g + n$ are minimised decision criteria.

3. Ranking of Facades' Alternatives: initial data and calculation results

The aim of the presented case study is to select the most preferable facade's alternative for public or commercial building, depending on a numerous set of quantitative and qualitative criteria. Criteria represent economy of decisions, performance parameters, environmental impact of particular facades' systems, structural properties and physical properties of structures. Criteria under consideration are installation cost, Lt/m^2 (x_1); labour intensity by assembling, days (x_2); user friendliness, points (x_3); durability, points (x_4); warranty, points (x_5); environmental friendliness, points (x_6); recovery (utilization), points (x_7); aesthetic, points (x_8); weight of structure, kg/m^2 (x_9); thickness of structure, mm (x_{10}); sound isolation, points (x_{11}); fire resistance, points (x_{12}). Criteria x_1, x_2, x_9 and x_{10} are minimized, while the remaining $x_3 – x_8$, x_{11} and x_{12} are maximized in a process of optimization.

Four building facades' alternatives are evaluated considering the above criteria and ranked, namely cellular concrete masonry covered by Rockwool plates and decorative plaster surface (a_1), "sandwich" facade panels (a_2), gas silicate masonry, covered by Rockwool and "Minerit" facade plates (a_3) and aluminium-glazing facade (a_4).

Relative significances of criteria (criteria weights) w_j are determined by means of Entropy method [23]. Calculations of relative significances for the current case study were presented in [11-12].

Initial decision making matrix for description of alternatives in terms of particular criteria is presented in Table 1.

Table 1. Initial decision making matrix

Alternatives a_i	Initial criteria values x_{ij}											
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
a_1	370.00	11.00	2.69	2.75	5.00	1.63	1.47	7.11	88.00	410.00	2.93	1.98
a_2	314.00	7.00	2.37	3.27	35.00	1.72	2.07	5.60	12.60	100.00	2.13	3.21
a_3	480.00	10.00	3.09	3.67	30.00	1.87	1.38	7.82	94.00	410.00	2.87	2.94
a_4	850.00	16.00	3.17	4.10	50.00	1.91	2.22	8.25	23.00	65.00	1.10	4.37
Weights w_j	0.0627	0.0508	0.1114	0.0874	0.0625	0.1183	0.0784	0.0984	0.0530	0.1417	0.0798	0.0557

Ranking of alternatives is performed applying WASPAS Eqs. (1-4) and Eq. (6), also the ratio system Equations (7), (8), the reference point approach Eq. (7), Eq. (9) and the full multiplicative form Eqs. (10-12). Established relative significances of alternatives are presented in Tables 2-3.

One can observe from calculation results that the most preferable alternative depends on λ value (Table 2). Alternative a_2 ("sandwich" facade panels) is ranked as the best and alternative a_4 (aluminium-glazing facade) remains in the second place in several cases among analyzed eleven variants with different λ values. While ranking order of the particular alternatives changes in several other cases and a_4 is preferred.

"Sandwich" facade panels are selected as the most preferable alternative when applying the ratio system, the reference point approach and the full multiplicative form (Table 3). The robustness of the latter methods is tested [17]. Accordingly, the results are reliable and applicable.

Table 2. Ranking of alternatives applying WASPAS

Alternatives a_i	Relative significances (ranks) of alternatives Q_i										
	λ = 0	λ = 0.1	λ = 0.2	λ = 0.3	λ = 0.4	λ = 0.5	λ = 0.6	λ = 0.7	λ = 0.8	λ = 0.9	λ = 1
a_1	0.4912 (4)	0.5033 (4)	0.5154 (4)	0.5274 (4)	0.5395 (4)	0.5516 (4)	0.5637 (4)	0.5758 (4)	0.5878 (4)	0.5999 (4)	0.6120 (4)
a_2	0.8173 (1)	0.8185 (1)	0.8197 (1)	0.8209 (1)	0.8221(1)	0.8233 (2)	0.8244 (2)	0.8256 (2)	0.8268 (2)	0.8280 (2)	0.8292 (2)
a_3	0.5873 (3)	0.5983 (3)	0.6093 (3)	0.6203 (3)	0.6313 (3)	0.6423 (3)	0.6532 (3)	0.6642 (3)	0.6752 (3)	0.6862 (3)	0.6972 (3)
a_4	0.8015 (2)	0.8066 (2)	0.8116 (2)	0.8167 (2)	0.8217 (2)	0.8268 (1)	0.8318 (1)	0.8369 (1)	0.8419 (1)	0.8470 (1)	0.8520 (1)

Table 3. Ranking of alternatives applying the ratio system, the reference point approach and the full multiplicative form

Alternatives a_i	Ratio system		Reference point		Full multiplicative form	
	$\bar{y}_i$	Rank	$\max\left\|r_j - \bar{x}_{ij} w_j\right\|$	Rank	U_i	Rank
a_1	0.1082	4	0.0825	3,4	2.9237E-07	4
a_2	0.2740	1	0.0179	1	2.2298E-04	1
a_3	0.1614	3	0.0825	3,4	3.6778E-06	3
a_4	0.2681	2	0.0308	2	6.3123E-05	2

It is possible to conclude that WASPAS results are partly coincident with the ratio system, the reference point approach and the full multiplicative form depending on λ value.

4. Conclusions

Four building facades' alternatives for public or commercial buildings were evaluated considering a set of twelve criteria in the presented case study.

Ranking of alternatives was performed applying WSM, WPM methods, a joint criterion of weighted aggregation of the latter methods, also the ratio system and the reference point approach as a parts of MOORA and the full multiplicative form. Fourteen series of ranks were calculated, respectively.

It was proved that the most preferable alternative depended on λ value when applying a joint weighted method WASPAS. Alternative a_2 ("sandwich" facade panels) was ranked as the best and alternative a_4 (aluminium-glazing facade) remained in the second place when λ=0,…,0.4. While ranking order of the particular alternatives changed their places and aluminium-glazing facade was preferred when λ=0.5,…,1.

MOORA method consisting of the ratio system and the reference point approach as well as the full multiplicative form were also applied for the case study. The best ranked alternative decisions coincided in the current case and "sandwich" facade panels were preferred.

Robustness of the ratio system, the reference point approach and the full multiplicative form were tested in previous researches. Accordingly, calculation results of the latter methods can be considered reliable.

Reliability of the joint criterion was tested and verification of results was performed when comparing it to MOORA. It was proved that WASPAS results coincided with the ratio system, the reference point approach and the full multiplicative form when λ=0,…,0.4. Hence the decision that "sandwich" panels are the best solution for public facade was justified.

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